VALVE TRAIN FOR INTERNAL COMBUSTION ENGINE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a valve train for an internal combustion engine, comprising a cam lobe fixed on a cam shaft, and a roller follower provided with a roller to be contacted with the cam lobe while rotating.

Description of the Related Art

Recently, from the viewpoint of the environment protection, low fuel consumption is highly requested. As to the internal combustion engine, the friction reduction more than the conventional ones is required for reducing the energy transmission loss in order to realize the low fuel consumption. According to a valve train comprising a cam follower for converting the rotating motion of the cam shaft to the reciprocal motion of the valve, a cam lobe fixed on the cam shaft is contacted with the cam follower while sliding or rotating. The friction loss between the cam lobe and the cam follower is one of the major factors of the friction loss in the entire internal combustion engine, and thus it is desired to reduce the same as much as possible. Therefore, various methods have been taken for the purpose of the friction reduction in the valve train.

For example, Japanese Patent Application Laid Open No. 2002-70507 discloses a method for reducing the resistance due to the friction, in which the slide-contacting type cam follower is allowed to have a surface layer with a lowered coefficient of dynamic friction by forming at least the area of the surface layer sliding against the cam lobe is formed with a diamond and making the surface roughness Ra of this area be 0.3 μm or less.

On the other hand, the low friction has been achieved by changing from the cam follower of the type of slide-contacting with the cam lobe (ex., flat tappet, or the like) to the roller follower of the type of rotation-contacting, such as a roller rocker arm and a roller tappet. Japanese Patent Application Laid Open No. 3-78507 discloses that a minute ruggedness of Ra in the range of 0.08 to 0.25 μm is formed on an outer circumferential surface of the rotation-contacting part (roller rim) of the roller follower with respect to the cam lobe which is a part coming in rotation-contact with the cam lobe to improve a performance of retaining a lubricant oil on such outer circumferential surface, thus preventing the abnormal wear.

Furthermore, Japanese Patent Application Laid Open No. 2001-329807 discloses that a surface roughness Ra of an outer circumferential surface of the cam lobe in the valve train is made 0.5 μm or less, and a surface roughness Ra of an outer circumferential surface of the rotation-contacting part (roller rim) of the roller on the roller rocker arm with respect to the cam lobe is made 0.1 μm or less to achieve prevention of pitching in the outer circumferential surface of the cam lobe and prevention

of peeling from the outer circumferential surface of the roller as well as reduction of wear on the outer circumferential surface of the cam lobe, and it also discloses that a surface roughness Ra of an outer circumferential surface of the cam lobe is made 0.5 μm or less to achieve reduction of aggressiveness (attacking) with respect to the outer circumferential surface of the rotation contacting part (roller rim) of the roller of the roller rocker arm with respect to the cam lobe.

SUMMARY OF THE INVENTION

However, the inventor of the present invention found the following fact. That is, in a rotation-contacting type combination of the cam lobe and the roller follower, the cam lobe and the roller follower are both abrasion products and accordingly low in the dynamic friction coefficient so that minute slippage is caused between the cam lobe and the roller follower and accordingly the efficient rotation is obstructed, thus leading a problem that the friction loss is caused.

In view of the above-mentioned circumstances, the present invention has been achieved, and an object thereof is to provide a valve train for an internal combustion engine, capable of eliminating the minute slippage between the cam lobe and the roller follower, and reducing the friction loss in the valve train system.

The present inventor has found out that the friction loss in the valve train system having a combination of a cam lobe

and a roller follower can be reduced by increasing the dynamic friction coefficient between the cam lobe and the roller follower so as to eliminate the minute slippage at the time of rotation-contact.

A first aspect of the present invention provides a valve train for an internal combustion engine, which comprises a cam lobe fixed on a cam shaft, and a roller follower provided with a roller to come in rotation-contact with the cam lobe, wherein the cam lobe is made of an iron based sintered material, and the surface roughness Ra of the outer circumferential surface thereof is in a range of 0.4 to 2.2 μm.

According to the valve train of the above-mentioned first aspect, it is preferable that the surface roughness Ra of the outer circumferential surface of the roller is in a range of 0.4 to 2.2 μm.

A second aspect of the present invention provides a valve train for an internal combustion engine, which comprises a cam lobe fixed on a cam shaft, and a roller follower provided with a roller to come in rotation-contact with the cam lobe, wherein the surface roughness Ra of the outer circumferential surface of the roller is in a range of 0.4 to 2.2 μm.

According to the valve train of the above-mentioned second aspect, it is preferable that the surface roughness Ra of the outer circumferential surface of the cam lobe is in a range of 0.4 to 2.2 μm.

Since the valve train of the present invention allows smooth rotation of the roller follower, the minute slippage between

the cam lobe and the roller follower can be eliminated, thus reducing the friction loss in the valve train system.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. 1 is a view showing a configuration example of a valve train for an internal combustion engine according to the present invention;

FIG. 2 is a view showing an example of a cam lobe.

FIG. 3 is an enlarged front view of an example of a contact part of a rocker arm with respect to a cam lobe;

FIG. 4 is a graph showing the transition of the friction characteristic (1,500 rpm) according to the combination between the cam lobe outer circumferential surface roughness and the roller outer circumferential surface roughness;

FIG. 5 is a graph showing the transition of the friction characteristic (2,000 rpm) according to the combination between the cam lobe outer circumferential surface roughness and the roller outer circumferential surface roughness;

FIG. 6 is a graph showing the transition of the friction characteristic (2,500 rpm) according to the combination between the cam lobe outer circumferential surface roughness and the roller outer circumferential surface roughness;

FIG. 7 is a graph showing the transition of the pitching characteristic according to the combination between the cam lobe outer circumferential surface roughness and the roller outer

circumferential surface roughness;

FIG. 8 is a view showing the configuration of a friction torque measuring device: and,

FIG. 9 is a view showing the configuration of a roller on roller rolling-and sliding wear tester device for measuring the number of pitching.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A valve train for an internal combustion engine according to the present invention comprises a cam lobe fixed on a cam shaft to be rotated synchronously with a crank shaft of an engine, and a roller follower provided with a roller to come in rotation-contact with the cam lobe. Herein, a term "rotation-contact" means that the roller is in contact with the cam shaft while the roller is rotating. The roller follower is a member provided with a roller to be in rotation-contact with a cam lobe at its part contacting with the cam lobe for converting the rotating motion of the cam shaft to the valve reciprocal motion, and it can be designed in a suitable form according to the structure of the valve operating mechanism. Examples of the roller follower include, a rocker arm (roller rocker arm) or a tappet (roller tappet) both of which are of the type provided with a roller at its contacting part with respect to the cam lobe, or another type in which a roller to be in rotation-contact with the cam lobe is directly mounted on the top end at the base part of the valve member, or the like.

FIG. 1 shows an embodiment of a valve train according to the present invention. The valve train of this embodiment is composed of a cam lobe 2 fixed on a cam shaft 1, and a rocker arm 3 provided with a roller 4 to be in rotation-contact with the cam lobe. The rocker arm 3 has a rocker arm main body 5, at one end part of which it supports the roller 4 rotatably by a pin 6, and the rocker arm 3 itself is supported swayably at a middle part of the main body 5 by a rocker shaft 7, and furthermore, an adjusting screw 8 which is screwed on the other end part of the rocker arm 3 butts against an end face of a base part of a valve body 9 by its top end part. A compression spring 10 applies an elastic force to the valve body 9 in the direction of closing an intake port or an exhaust port.

FIG. 2 includes a front view (2A) and a side view (2B) respectively showing an example of the shape of the cam lobe 2. FIG. 3 is an enlarged front view of an example of the contact part of the rocker arm 3 at which it comes in contact with the cam lobe 2. The rocker arm 3 supports the roller 4 rotatably in the following manner: a pair of supporting wall parts 5a each having a bearing hole 5b and positioning with an interval therebetween is formed on one end part of the rocker arm main body 5, at which the rocker arm main body 5 comes into contact with the cam lobe 2, the roller 4 having a bearing hole 4a is disposed between the pair of the supporting wall parts 5a, and the pin 6 is inserting through one bearing hole 5b of the supporting wall parts, the bearing hole 4a of the roller 4, and then the other bearing hole 5b of the supporting wall parts. Moreover,

it is preferable to put a bearing between the pin 6 and the bearing hole 4a and/or the bearing hole 5b for alleviating the friction loss. Although the material of the roller 4 is not particularly limited, and for example, a bearing steel such as the bearing steel SUJ2, or the like is preferable.

According to the present invention, at least one of the measures described below is applied to the valve train in order to rotate the roller smoothly without causing the minute slippage at the time of bringing the cam lobe 2 of the cam shaft into rotation-contact with the roller 4 of the roller follower.

Measure 1: A cam lobe made of an iron sintered material is used, and the surface roughness Ra of the outer circumferential surface thereof is made to be in a range of 0.4 to 2.2 μm, preferably 0.4 to 1.2 μm, and particularly preferably 0.85 to 1.2 μm.

Measure 2: The surface roughness Ra of the outer circumferential surface of the roller of the roller follower (the contacting surface with respect to the cam lobe) is made to be in a range of 0.4 to 2.2 μm, and preferably 0.4 to 1.2 μm.

In the case of taking the above-mentioned measure 1, the dynamic friction coefficient of the contact surface between the cam lobe and the roller is increased by using an iron based sintered material for forming the cam lobe and further setting the surface roughness Ra of the outer circumferential surface to 0.4 μm or more. Such increase of the dynamic friction coefficient can prevent the minute slippage therebetween, thus alleviating the friction loss of the valve train system. In addition to such

intention of obtaining the appropriate dynamic friction coefficient for preventing the minute slippage in the rotation-contacting surface, in order to restrain the pitching wear by preventing the deterioration of the pitching resistance due to a large surface pressure loaded on a localized portion in the rotation-contacting surface, the surface roughness Ra of the outer circumferential surface on the cam lobe is set to 2.2 μm or less.

As the sintered cam lobe for the first measure, one made of any iron based sintered alloy such as a Mo-Ni-Fe based one, and a Mo-Ni-Cr-Fe based one can be used. Moreover, as the iron based sintered alloy, those having a porosity about 2 to 10% can be used from the viewpoint of the strength, the wear resistance or the like of the cam lobe. In the case when the surface roughness Ra of the outer circumferential surface (the contacting surface with the cam lobe) of the roller 4 is also set within a range of 0.4 to 2.2 μm, in particular 0.4 to 1.2 μm in addition to control of that of the outer circumferential surface on the cam lobe, the friction loss can further be alleviated while restraining the increase of the pitching wear, and thereby the minute slippage between the cam lobe and the roller can further be restrained to the lower degree, thus being preferable. Although the material of the roller 4 is not particularly limited, for example, a bearing steel, such as the bearing steel SUJ2 is preferable.

On the other hand, in the case of taking the above-mentioned measure 2, the dynamic friction coefficient of the contact surface

between the cam lobe and the roller is increased by setting the surface roughness Ra of the outer circumferential surface on the roller to 0.4 μm or more. Such increase of the dynamic friction coefficient can prevent the minute slippage therebetween, thus alleviating the friction loss of the valve train system. In addition to such intention of obtaining the appropriate dynamic friction coefficient for preventing the minute slippage in the rotation-contacting surface, in order to restrain the pitching wear by preventing a large surface pressure from being loaded on a localized portion in the rotation-contacting surface, the surface roughness Ra of the outer circumferential surface on the roller is set to 2.2 μm or less.

For the second measure, although the material of the cam lobe 2 is not particularly limited, any material known for the conventional cam lobe may be used, and examples thereof include an iron based sintered alloy, a carbon steel S50C (it may be subjected to high frequency quenching), or the like. In the case when the surface roughness Ra of the outer circumferential surface (the contacting surface with the roller) on the cam lobe 2 is also set within a range of 0.4 to 2.2 μm, in particular, 0.4 to 1.2 μm, in addition to control of that of the outer circumferential surface of the roller, the friction loss can further be alleviated while restraining the increase of the pitching wear, and thereby the minute slippage between the cam lobe and the roller can further be restrained to the lower degree, thus being preferable.

It is preferable to execute the above-mentioned measures

1 and 2 in combination with each other since the effect of reducing the friction loss can further be improved.

The method for controlling the surface roughness of each contact surface on the roller and the cam lobe in the above-mentioned range is not particularly limited, and various surface works can be applied, for example, the grinding work such as cross hatching, and blasting work such as shot blasting which is a method of blowing the hard particles such as the metal particles and the ceramic particles at the high speed and high pressure. In the case of applying the blast work, shot blasting is suitable, and particularly suitable condition for the shot blasting is to jet the steel grids having a 44 μm average particle size by 0.44 to 0.55 MPa.

Moreover, the cam lobe after sintering process may be subjected to a refining process as needed, and the cam lobe subjected to such process may be used as it is without applying the blast work.

As heretofore explained, according to the valve train of the present invention, since the roller of the roller follower can be rotated smoothly, the minute slippage between the cam lobe and the roller follower is eliminated so that the friction loss in the valve train system can be reduced.

EXAMPLES

The transitions of the friction characteristic and the pitching characteristic according to the various combination

of the iron based sintered material cam lobes having different surface roughnesses Ra of the outer circumferential surface and the SUJ2 quenched steel rollers having different surface roughnesses Ra of the outer circumferential surface were examined.

<Production method>

The sintering powder were prepared such that the element composition after secondary sintering was adjusted to C: 0.8% by mass, Mo: 0.5% by mass, Ni: 2.5% by mass, and Fe: remainder. Furthermore, as the lubricating agent, a zinc stearate was added and mixed.

Next, a temporary sintered compact was obtained by executing first press molding (primary molding) the prepared sintering particles by a 500 to 800 Mpa (5 to 8 ton/cm^2) surface pressure so as to form a green compact, and by executing temporary sintering (primary sintering) the green compact at 600°C to 900°C in a vacuum sintering furnace. Then, a secondary sintered compact was obtained by executing second press molding (secondary molding) the temporary sintered compact by a 700 to 1200 Mpa (7 to 12 ton/cm^2) surface pressure, and by executing main sintering (secondary sintering) the secondary compact at 1,100°C to 1,200°C in a vacuum sintering furnace. This secondary sintered compact was further subjected to the quench and temper process, and then grinding finish process of the outer circumferential surface, thereby obtaining a cam lobe made of an iron based sintered material which had an outer circumferential hardness at 52 HRC, a density at 7.46 Mgm^{-3}, and a surface roughness Ra of the outer

circumferential surface in the range of 0.2 to 2.2 μm.

On the other hand, a bearing steel SUJ2 shaped in a roller was subjected to the quench and temper process, and then grinding finish process of the outer circumferential surface, thereby obtaining a roller having an outer circumferential hardness at 61 HRC, and a surface roughness Ra of the outer circumferential surface in the range of 0.2 to 2.2 μm.

<Measurement of the friction torque>

The friction torque was measured for the cam lobes and the rollers obtained by the above-mentioned production method in the combinations shown in the Tables 1 to 3 by the following method and condition. The combinations shown in the Tables 1 to 3 are encoded as shown in the Tables 4 to 6.

Using the apparatus having the configuration shown in FIG. 8, the force Fz in the horizontal direction (the direction perpendicular to the cam shaft) of the roller circumference, the friction force Fy with respect to the guide part 12, and the force Fx in the cam shaft direction were measured by a three component force sensor 13, and the load Fp of the push rod 11 was measured by a force sensor 14. The friction torque Ff was calculated from the measurement results and the contact angle α and the contact load Fc between the cam lobe and the roller, and using the below-mentioned formula.

$$Fc \sin\alpha + Ff \cos\alpha = Fz$$

$$Fc \cos\alpha - Ff \sin\alpha = Fy + Fp + Fx$$

The results are shown in the Table 1 and FIG. 4, the Table 2 and FIG. 5, and the Table 3 and FIG. 6.

(Measurement condition)

Roller size: the contact part with the cam lobe of the roller rocker arm having a 34 mm cylinder size provided with the roller part having a 28 mm outer diameter and a 17 mm width

Cam lobe size: basic circle radius 23 mm, lifting amount 7.9 mm

Lubricant oil: SAE10W-30

Oil temperature: 90°C

Oil pressure: 0.3 MPa

Cam rotation speed: 1,500 rpm, 2,000 rpm, 2,500 rpm

<Measurement of Cycle times leading to Occurrence of Pitching>

The cycle times leading to the occurrence of pitching was measured for the combinations of the cam lobe materials and the roller materials shown in the Table 7 by means of a roller on roller rolling-and sliding wear tester machine shown in FIG. 9, using the cam lobe material having a surface roughness Ra of the outer circumferential surface of 0.2 to 2.2 μm, and the roller material having a surface roughness Ra of the outer circumferential surface of 0.2 to 2.2 μm produced in the same manner as the above-mentioned production method.

With the cam lobe material and the roller material installed in the testing machine, the cycle times of the rotation at which the pitching was caused was measured in the following manner:

the outer circumferential surface on the cam lobe iron based sintered material (test piece 15) of the cam shaft and that on the roller (counterpart cylindrical test piece 16) of the roller rocker arm were brought into contact with each other under 3,000 N of the applied lord (load 18); the rotation of the cam lobe iron based sintered material (test piece 15) was started at a constant rotation frequency (rotation speed) while a lubricant oil 17 was dropped to the contact surface between the test pieces; and then the cycle times of rotation was counted till occurrence of the pitching. The results are shown in the Table 7 and FIG. 7. The combinations shown in the Table 7 are encoded as shown in the Table 8.

(Measurement condition)

Test machine: roller on roller rolling-and sliding wear tester

Rotation speed: 1,500 rpm

Lubricant oil: SAE10W-30

Oil temperature: 100°C

Amount of lubricant oil supplied: 2×10^{-4} m^3/min

Load: 3,000 N

Slipping ratio: 0%

Judgment method: The occurrence of cracks due to the pitching was detected by the AE (acoustic emission), and the cycle times when the occurrence of cracks was detected was defined as the cycle time leading to the pitching.

<Test results>

As shown in the Tables 1 to 3 and FIGS. 4 to 6, the friction

torque was smaller in the combination having a larger surface roughness Ra of the cam lobe and the roller.

Specifically, the friction torque (Ff (0.2/0.2)) of the combination with the surface roughness Ra of the outer circumferential surface of the cam lobe of 0.2 μm and the surface roughness Ra of the outer circumferential surface of the roller of 0.2 μm, that is, the combination with the surface roughness Ra of the outer circumferential surface of the cam lobe of less than 0.4 μm and the surface roughness Ra of the outer circumferential surface of the roller of less than 0.4 μm was 0.28 N·m, 0.19 N·m, and 0.15 N·m, respectively at the 1,500 rpm, 2,000 rpm and 2,500 rpm. Although the friction torque in this case tends to be reduced with the rise of the rotational frequency, since the surface roughness Ra of the outer circumferential surface of the cam lobe and the surface roughness Ra of the outer circumferential surface of the roller are both small, the minute slippage accompanied by the decline of the dynamic friction coefficient in the contact surface between the cam lobe and the roller was caused so that the friction torque as a whole was high, and thus the friction loss was not reduced sufficiently.

In contrast, the friction torque (Ff (2.2/2.2)) of the combination with the surface roughness Ra of the outer circumferential surface of the cam lobe of 2.2 μm and the surface roughness Ra of the outer circumferential surface of the roller of 2.2 μm was 0.12 N·m, 0.08 N·m, and 0.07 N·m, respectively at the 1,500 rpm, 2,000 rpm and 2,500 rpm. The friction torque in this case tends to be reduced with the rise of the rotational

frequency. Since this case has a combination with the surface roughness Ra of the outer circumferential surface of the cam lobe and the surface roughness Ra of the outer circumferential surface of the roller are both large, the dynamic friction coefficient in the contact surface between the cam lobe and the roller is high so that the friction torque was small as a whole. The improvement ratio (Ff (2.2/2.2)/Ff (0.2/0.2)) of the friction torque (Ff (2.2/2.2)) in the combination of the surface roughnesses Ra of the cam lobe and the outer circumferential surface of the roller of both 2.2 μm with respect to the friction torque (Ff (0.2/0.2)) in the combination of the surface roughnesses Ra of the cam lobe and the outer circumferential surface of the roller of both 0.2 μm was each about 4.3/10, 4.2/10 and 4.7/10, respectively at the 1,500 rpm, 2,000 rpm and 2,500 rpm. By increasing the surface roughness Ra of the outer circumferential surfaces of the cam lobe and the roller, reduction of the friction loss was achieved.

As mentioned above, by increasing the surface roughness Ra of the outer circumferential surfaces of the cam lobe and the roller so as to control them at 0.4 or more, the friction torque can be reduced to the extremely small degree.

Table 1 Transition of Friction torque (Cam rotation speed: 1,500 rpm)

Friction torque (N·m)		Outer circumferential surface roughness Ra of Roller part of Roller follower (μm) Material: quenched SUJ2						
		0.2	0.4	0.8	1.2	1.6	2.0	2.2
Outer	0.2	0.28	0.28	0.27	0.27	0.26	0.25	0.25
circumferential	0.4	0.25	0.25	0.24	0.24	0.23	0.23	0.23
surface	0.8	0.20	0.18	0.17	0.16	0.15	0.15	0.14
roughness Ra of	1.0	0.18	0.17	0.16	0.15	0.15	0.14	0.13
Cam lobe (μm)	1.4	0.17	0.17	0.16	0.15	0.14	0.13	0.13
Material: iron	1.8	0.16	0.16	0.15	0.14	0.14	0.13	0.13
based sintered	2.0	0.16	0.16	0.15	0.14	0.13	0.13	0.12
material	2.2	0.15	0.15	0.15	0.14	0.13	0.13	0.12

Table 2 Transition of Friction torque (Cam rotation speed: 2,000 rpm)

Friction torque (N·m)		Outer circumferential surface roughness Ra of Roller part of Roller follower (μm) Material: quenched SUJ2						
		0.2	0.4	0.8	1.2	1.6	2.0	2.2
Outer	0.2	0.19	0.18	0.18	0.17	0.16	0.16	0.15
circumferential	0.4	0.17	0.15	0.15	0.14	0.13	0.13	0.12
surface	0.8	0.14	0.14	0.13	0.13	0.11	0.10	0.10
roughness Ra of	1.0	0.13	0.13	0.12	0.12	0.11	0.10	0.09
Cam lobe (μm)	1.4	0.11	0.11	0.10	0.10	0.09	0.09	0.09
Material: iron	1.8	0.11	0.11	0.10	0.10	0.09	0.09	0.09
based sintered	2.0	0.11	0.10	0.10	0.09	0.09	0.09	0.09
material	2.2	0.10	0.10	0.09	0.09	0.09	0.09	0.08

Table 3 Transition of Friction torque (Cam rotation speed: 2,500 rpm)

Friction torque (N·m)		Outer circumferential surface roughness Ra of Roller part of Roller follower (μm) Material: quenched SUJ2						
		0.2	0.4	0.8	1.2	1.6	2.0	2.2
Outer	0.2	0.15	0.15	0.15	0.14	0.13	0.13	0.13
circumferential	0.4	0.14	0.13	0.12	0.12	0.12	0.12	0.11
surface	0.8	0.11	0.10	0.10	0.10	0.10	0.10	0.10
roughness Ra of	1.0	0.11	0.10	0.10	0.10	0.10	0.10	0.10
Cam lobe (μm)	1.4	0.10	0.10	0.10	0.10	0.09	0.09	0.09
Material: iron	1.8	0.09	0.09	0.09	0.09	0.09	0.09	0.08
based sintered	2.0	0.09	0.09	0.09	0.08	0.08	0.08	0.08
material	2.2	0.08	0.08	0.08	0.08	0.08	0.07	0.07

Table 4 Combination in the Table 1 (Cam rotation speed: 1,500 rpm)

Friction torque (N·m)		Outer circumferential surface roughness Ra of Roller part of Roller follower (μm) Material: quenched SUJ2						
		0.2	0.4	0.8	1.2	1.6	2.0	2.2
Outer	0.2	A1	B1	C1	D1	E1	F1	G1
circumferential	0.4	A2	B2	C2	D2	E2	F2	G2
surface	0.8	A3	B3	C3	D3	E3	F3	G3
roughness Ra of	1.0	A4	B4	C4	D4	E4	F4	G4
Cam lobe (μm)	1.4	A5	B5	C5	D5	E5	F5	G5
Material: iron	1.8	A6	B6	C6	D6	E6	F6	G6
based sintered	2.0	A7	B7	C7	D7	E7	F7	G7
material	2.2	A8	B8	C8	D8	E8	F8	G8

Table 5 Combination in the Table 2 (Cam rotation speed: 2,000 rpm)

Friction torque (N·m)		Outer circumferential surface roughness Ra of Roller part of Roller follower (μm) Material: quenched SUJ2						
		0.2	0.4	0.8	1.2	1.6	2.0	2.2
Outer circumferential surface roughness Ra of Cam lobe (μm) Material: iron based sintered material	0.2	H1	I1	J1	K1	L1	M1	N1
	0.4	H2	I2	J2	K2	L2	M2	N2
	0.8	H3	I3	J3	K3	L3	M3	N3
	1.0	H4	I4	J4	K4	L4	M4	N4
	1.4	H5	I5	J5	K5	L5	M5	N5
	1.8	H6	I6	J6	K6	L6	M6	N6
	2.0	H7	I7	J7	K7	L7	M7	N7
	2.2	H8	I8	J8	K8	L8	M8	N8

Table 6 Combination in the Table 3 (Cam rotation speed: 2,500 rpm)

Friction torque (N·m)		Outer circumferential surface roughness Ra of Roller part of Roller follower (μm) Material: quenched SUJ2						
		0.2	0.4	0.8	1.2	1.6	2.0	2.2
Outer circumferential surface roughness Ra of Cam lobe (μm) Material: iron based sintered material	0.2	O1	P1	Q1	R1	S1	T1	U1
	0.4	O2	P2	Q2	R2	S2	T2	U2
	0.8	O3	P3	Q3	R3	S3	T3	U3
	1.0	O4	P4	Q4	R4	S4	T4	U4
	1.4	O5	P5	Q5	R5	S5	T5	U5
	1.8	O6	P6	Q6	R6	S6	T6	U6
	2.0	O7	P7	Q7	R7	S7	T7	U7
	2.2	O8	P8	Q8	R8	S8	T8	U8

As shown in the Table 7 and FIG. 7, the cycle times leading to the occurrence of pitching (number of pitching occurrence) was smaller in the combination with a larger surface roughness Ra of the outer circumferential surface of the cam lobe and the roller so that the pitching resistance was lowered.

Specifically, in the combination of the surface roughness Ra of the outer circumferential surface of the cam lobe of 2.2 μm and the surface roughness Ra of the outer circumferential surface of the roller of 2.2 μm, the number of pitching occurrence was 5.0×10^5, and it was smallest.

In contrast, according to a past experience of the present inventor, when the conventional chilled cast iron cam shaft is used in combination with the roller follower, the number of the pitching occurrence is about 1.3×10^5 under 3,000 N in the test

condition, so that the excellent pitching characteristic cannot be obtained, the durability is insufficient, and thus it is not suited for the long term use.

That is, even in the case of the combination of the surface roughness Ra of the outer circumferential surface of the iron based sintered material cam lobe of 2.2 µm and the surface roughness Ra of the outer circumferential surface of the roller of 2.2 µm, which has the smallest number of pitching occurrence among the combinations shown in the Table 7, the number of the pitching occurrence can be improved by about 4 times compared with the case of using the chilled cast iron cam shaft in combination with the roller follower. Furthermore, according to the combination of having the surface roughness Ra of the outer circumferential surface of the iron based sintered material cam lobe and the roller of less than 2.2 µm, the number of the pitching occurrence is improved over 4 times.

That is, by controlling the outer circumferential surface Ra on the outer circumferential surface of the cam lobe and the roller at 2.2 µm or less, the high friction characteristic can be provided and at the same time the excellent pitching resistance can be obtained.

In contrast, according to the combination of the surface roughness Ra of the outer circumferential surface of the cam lobe of 0.2 µm and the surface roughness Ra of the outer circumferential surface of the roller of 0.2 µm, that is, the combination of the surface roughness Ra of the outer circumferential surface of the cam lobe of less than 0.4 µm,

and the surface roughness Ra of the outer circumferential surface of the roller of less than 0.4 μm, the number of the pitching occurrence was 2.0×10^7, so that the excellent pitching resistance can be demonstrated. However, in the above-mentioned measurement of the friction torque, the friction torque was high in this combination.

Table 7 Transition of Number of Pitching Occurrence (Contact load: 3,000N)

Number of pitching occurrence		Outer circumferential surface roughness Ra of Roller part of Roller follower (μm) Material; quenched SUJ2				
		0.2	1.0	1.8	2.0	2.2
Outer circumferential surface roughness Ra of Cam lobe (μm) Material: iron based sintered material	0.2	2.0×10^7	8.8×10^6	5.0×10^6	4.2×10^6	3.6×10^6
	1.0	9.1×10^6	6.2×10^6	4.1×10^6	3.3×10^6	2.1×10^6
	1.8	5.5×10^6	4.7×10^6	3.1×10^6	2.1×10^6	1.2×10^6
	2.0	5.0×10^6	4.1×10^6	1.2×10^6	9.2×10^5	8.0×10^5
	2.2	3.8×10^6	3.2×10^6	9.5×10^5	7.0×10^5	5.0×10^5

Table 8 Combination in the Table 7

Number of Pitching Occurrence		Outer circumferential surface roughness Ra of Roller part of Roller follower (μm) Material: quenched SUJ2				
		0.2	1.0	1.8	2.0	2.2
Outer circumferential surface roughness Ra of Cam lobe (μm) Material: iron based sintered material	0.2	V1	W1	X1	Y1	Z1
	1.0	V2	W2	X2	Y2	Z2
	1.8	V3	W3	X3	Y3	Z3
	2.0	V4	W4	X4	Y4	Z4
	2.2	V5	W5	X5	Y5	Z5

From the results of the Tables 1 to 3, and FIGS. 4 to 7, it was learned that the combination with the larger surface roughness Ra of the outer circumferential surfaces of the cam lobe and the roller was advantageous for improving the effect of reducing the friction loss, however, in contrast, the pitching characteristic was deteriorated in the combination with the larger surface roughness Ra of the outer circumferential surfaces

of the cam lobe and the roller part. The balance of the friction characteristic and the pitching characteristic was particularly preferable when both of the surface roughness Ra on the outer circumferential surface of the cam lobe and the roller were in a range of 0.4 to 2.2 μm.